

A Coronal Jet Ejects from Sunspot Light Bridge

S. Liu¹

National Astronomical Observatory,
Chinese Academy of Sciences, Beijing, China

lius@nao.cas.cn

Received _____; accepted _____

Not to appear in Nonlearned J., 45.

¹key Laboratory of Solar Activity

ABSTRACT

Chromospheric brighten and $H\alpha$ surge are the evident and common phenomena along sunspot light bridge. In this paper, a coronal jet ejects from sunspot light bridge is presented. Using the data from the Solar Dynamics Observatory (SDO) and Hinode satellites, it is confirmed that the jet has the root near light bridge, this suggests that the jet may be a result of reconnection between main sunspot and light bridge. Due to the processing of jet ejects, the intensity and width of light bridge have some changes at some extent. This also suggests that jet is related to the interaction between light bridge and umbra, possibly magnetic reconnection or heat plasma trapped in light bridge escaping and moving along field line.

Subject headings: Sunspot, Light bridge, Coronal jet

1. Introduction

Light bridge (LB) is bright structures crossing the umbra during the evolution of sunspots. LB is associated to the breakup of sunspots in the decay or the assembly of sunspots in complex active regions (Bray et al. 1964; Vasquez 1973; Garcia de La Rosa 1987). Muller (1979) classified LB as "photospheric," "penumbral," and "umbral" LB according its intensity and fine structure. Another classification is as follows (Sobatka et al. 1993, 1994): strong LB, which separates umbral core and is further distinguished as photospheric or penumbral, and faint LB, which is faint narrow lane with in the umbra and most likely consists of umbral dots.

At present, the formation and magnetic properties of LB are not understood completely. A common mechanism to explain the formation of LB is that field-free convection penetrates umbra from sub-photosphere and forms a cusp-like magnetic field (Spruit & Scharmer 2006). Katsukawa et al. (2007b) revealed the formation of a LB due to the intrusion of umbral dots basing on data obtained from *Hinode* satellite. Magnetic field in LB is revealed weaker and more inclined than that of surround umbra (Ruedi et al. 1995; Leka 1997; Jurcak et al. 2006). **Based** on *Hinode* observation of the magnetic field in a LB accompanied by long-lasting chromospheric plasm ejections, Shimizu et al. (2009) suggest that current-carrying highly twisted magnetic flux tubes are trapped below a cusp-shape magnetic structure along the LB. In addition, by a detail analysis of the Stokes spectra (Jurcak et al. 2006), it is found that the field strengths and inclinations increase and decrease with height, which suggest a canopy-like structure above the LB.

It is undoubted that the plasm contained in LB have a temperature higher than that in surrounding umbra because of the brightness of LB. Observations indicate that there are remarkable plasma ejections or $H\alpha$ surge activities in chromosphere along LB (Roy 1973; Asai 2001; Bharti et al. 2007; Shimizu et al. 2009). Additionally, over the

site of LB the bright enhancement in 1600 Å images and heating of coronal loops in 171 Å images from Transition Region and Coronal Explorer (**TRACE**) was founded recently (Berger & Berdyugina 2003; Katsukawa 2007), which observations suggest that LB is a steady heat source in the chromosphere. Louis et al. (2008) using G-band and Ca II images obtained from *Hinode* studied dynamics and brightness enhancements of LB, and pointed to the possibility that LB could be the sites for heating the overlying chromosphere, but can not rule out the likelihood of coronal phenomena. In this paper, a coronal jet originates from the site of LB is presented, which means that the interaction between LB and umbra can also create coronal dynamic activities.

The paper is organized as follows: firstly, the description of observations and data used will be introduced in Section 2; secondly, the results are shown in Section 3; at last, the short discussions and conclusions will be given in section 4.

2. Observations and Data Reduction

Jet studied here is near disk center (heliographic coordinates S17W23), it occurred during about 20:00-21:00 UT on 29 Mar 2011. The observatory data, which used to study this jet, were obtained by Atmospheric Imaging Assembly (AIA) (Title et al. 2006; Boerner et al. 2010) and Helioseismic and Magnetic Imager (HMI) (Schou et al. 2010) on board the SDO and by Solar Optical Telescope (SOT) on board *Hinode* (Kosugi et al. 2007; Tsuneta et al. 2008). AIA takes full-disk image in 10 wavelengths with a pixel size of 0.59 arcsec. In this paper, AIA 171 Å and 1700 Å data at Level 1 with 45 s cadence is used. HMI includes full-disk magnetograms, continuum intensities, dopplergrams with spatial resolution of 0.5 arcsec. In this paper, light-of-sight (LOS) magnetograms and continuum intensity are used for this analysis. G-band and Ca II (with spatial resolution of 0.1 arcsec) and LOS magnetogram (with spatial and temporal resolution 0.16 arcsec and 15

min, respectively) observed by SOT/*Hinode* are used in this work. The data processing in the work are all based on standard solar software (SSW *e.g.* fg_prep.pro, aia_prep.pro). For example, dark subtraction, flat fielding, the correction of bad pixels and cosmic-ray removal were done for filtergram images obtained by SOT.

3. Results

Fig 1 shows the location of this jet, it occurs during about 20:00-21:00 UT on 29 Mar 2011. The left image is full-disk AIA 171 Å image at 20:40 UT, and the region where jet occurs is drawn by a white rectangle, the right image is amplified sub-region of left image, where the jet (highlight by white region) can be seen obviously. It is found that the jet has already separated in two parts along its direction of propagation as time going on, the former part ejects toward space and the latter one falls back along magnetic field lines where it created.

Fig 2 shows the process of coronal jet from 20:00 to 21:07 UT, with peak at 20:45 UT using AIA 171 Å images. The field of view is 162 arcsec for all images. The blue arrow in each frame points to the evolution of this jet, includes the start (a, b), maximum (c, d) and decay (e, f) phases. In image (d) the jet has already separated two parts along its direction of propagation, the former part (yellow arrow) ejects toward space away from the Sun, the latter one (blue arrow) becomes a back-flow along magnetic field lines and gives rise to the intensity enhancement of the site where jet originated, which can be seen in image (e) indicates by a red arrow. The velocity of back-flow is about 198 km/s, which is calculated from these AIA 171 Å images, however the effect of project are not considered. To see the intensity enhancement resulted from the back-flow, Fig 3 shows the evolution of 1700 Å images from 20:53 to 20:59 UT. The intensity enhancement indicated by a blue arrow in panel (e) should be caused by the back-flow corresponding the latter part of jet.

In order to know the circumstances of lower atmosphere corresponding to the site where jet created, Fig 4 gives the AIA 171 Å (a) and 1700 Å (b) images, HMI LOS magnetogram (c) and continuum intensity (d) images and G-band (e) and Ca II (f) SOT/*Hinode* images together. These images are aligned by heliospheric coordinate and combined by correlation of feature points (cross-correlation function IDL). The contour lines plotted on each image are LOS magnetic field, where the levels of magnetic field contours are -80 to -50 and 200-800 G, and red/green contours are positive/negative magnetic flux, while in image (f) the yellow contour are positive one, the blue rectangle indicates the site of jet originated. From the continuum intensity, G-band and 1700 Å image, it can be seen clearly that the jet has its root near LB, which can be seen from the intensity enhancement of image (b) and (f) indicated by a white arrow, this intensity enhancement is due to mass falling back along magnetic field lines. Additionally, from image (c) it can be found that there is no evident negative magnetic flux, which opposite the main positive magnetic flux nearby the root of jet. To see the fine structure of magnetic field on the photospheric associated with jet eruption more clearly, the high spatial resolution (0.16 arcsec) LOS magnetic field observed by SOT/*Hinode* is shown in Fig 5, here the field of view is 40×40 arcsec². Where the levels of magnetic field contours are -80 to -50 and 200-800 G, and red/green contours are positive/negative magnetic flux, which is consistent with those of HMI LOS magnetic field in Fig 5. It is found that there is no evident negative magnetic flux near the site where jet eruption from the high spatial resolution images of LOS magnetic field.

In order to find the change in LB during jet ejected, the evolution of maximal intensity and width of LB are studied using 1700 Å images. Six slits are selected along LB (the right image of Fig 6, which is an example observed at time 20:30:08 UT). The profile of intensity of each slit is fitted using Gaussian function, then the half width and the height of Gaussian function is as the width and maximal intensity of LB, respectively (in left image of Fig 6, the dot line is profile of intensity and the solid line is Gaussian fit to the intensity,

the numbers of slit are corresponding those of the profile of intensity labeled using different color). It can be found that the results of Gaussian fit are reasonable and acceptable, because there is no evident deviations between the true profiles and the fitted profile.

Using the above method to calculate a serial of 1700 Å images, the evolution of maximal intensity and width of LB are plotted in Fig 7 and 8, respectively, during 16:00-22:30 UT. The time interval between two yellow vertical lines is 20:00-21:00 UT. From Fig 7, it can be found that before jet creates there is no evident changes of maximal intensity; by the time of jet onset the maximal intensity begin to increase slightly, but this increase is not evident; during the jet ejects the evolutions of maximal intensity are different among six slits, for slit of (1) (2) and (3) it increase slightly but not evidently, for slit of (4), (5) and (6) it do not change almost, however on the whole they have a trend of increase for maximal intensity during jet ejects; when jet finishes the maximal intensity reach to maximum, which is caused by the back-flow of jet, after that time it begin to decrease. From Fig 8, it can be found that before and during jet ejects there is no evident rule can be obtained, however after jet finishes there is a jump of the width of LB, which is also caused by the back-flow of jet, and then narrows down to normal width as before quickly. The above results confirm that this jet has its root near LB, thus, the interaction between LB and main sunspot may be a direct reason for the creation of this jet. The width of LB (≈ 500 Km) plotted in Fig 8 is consistency the previous result (Louis et al. 2008).

The HMI continuum intensity images are also studied by the same method as above to know the properties of LB on photosphere during jet erupts. Similar to Fig 6, six slits in continuum intensity image are selected and shown in the right frame of Fig 9, where the observation obtained at the time 20:29:59 UT is used as an example. After Gaussian fit for a serial of continuum intensity images, the evolution of maximal intensity and width of LB on the photosphere are plotted in Fig 10 and 11, respectively. On the whole, the maximal

intensities increase slightly before and during jet ejections, then they display a decrease after jet finishes. On the photosphere the change trend of the width of LB can not be ruled out before and during jet ejection, and different slits show different changes. However, there is a common fact that the width of LB is broadened to some extent after jet finishes. It is also found that the width of LB on the photosphere (≈ 800 Km) is broader than that of the 1700\AA image (≈ 500 Km).

4. Discussions and Conclusions

Using multi-spectral images observed by *Hinode* and SDO newly launched satellites, the evolution of a LB accompanying coronal jet eruption is studied. It is revealed that this coronal jet (ejected during 20:00 to 21:07 UT on Mar 29 2011, with peak at 20:45 UT) is related to LB. It suggests that interaction between LB and main umbra not only has low atmospheric response (previous studies include $H\alpha$ surge, coronal loops enhancement) but can also have more dynamic high atmospheric or coronal activities.

The evolutions of LB during jet eruption are studied basing on the 1700\AA images and photospheric continuum intensity images in this paper. On the whole the intensity and width of LB show no evident change before and during jet ejection, however there are evident changes after jet finishes, which means that LB can also have dynamic coronal response not only chromospheric response (chromospheric brighten and $H\alpha$ surge). It is also found that the width of LB displayed on the photosphere is broader than that displayed on 1700\AA image. The evolutions of intensity and width of LB at different atmospheres can only give us a change trend during jet ejections. It is noted that LB accompanying coronal jet is seldom for study so far. Thus, it is expected that more available scientific data for similar analysis in the not far future.

Normally jet is regarded as the phenomenon of magnetic reconnection. The existence of opposite magnetic flux is required for reconnection models, but from light-of-sight magnetic field it is found that there is no evident opposite magnetic flux exist in the region where jet originated for this event. Thus, there should be the magnetic components in LB that can provide the essential condition for magnetic reconnection. Accurately, the basic condition for magnetic reconnection is the opposite magnetic flux and anomalous resistance. Generally, the opposite magnetic flux in fact is two magnetic topologies and the anomalous resistance is usually caused by some instabilities. Here, the main sunspot and the LB can be considered two magnetic systems and the instability maybe more easily exist at the boundary between main sunspot and LB. For this jet event, the opposite magnetic flux maybe below the resolution of magnetic field observed. Or like Shimizu et al. (2009), highly twisted magnetic field is trapped in LB that can provide condition for magnetic reconnection. Also it should be noted that magnetic reconnection does not always require the opposite magnetic flux, such as component reconnection (there are some angle differences between the two magnetic components). However there may be more deep physics mechanism for magnetic reconnection, which can be studied in future, when we get high spatial and temporal resolution vector magnetic field that can show more fine magnetic structure of LB.

Plasma and magnetic field fill the whole Sun, and there is a phenomenon of magnetic freezing in the region of strong magnetic field (namely, the region of sunspot). Hence, the plasma should flow along magnetic field line. Sunspot and LB should be considered as two magnetic systems. Previous studies (Ruedi et al. 1995; Leka 1997; Jurcak et al. 2006) show that magnetic field in LB is weaker and more inclined than that of surrounding umbra. For a unipolar sunspot studied here, the magnetic field line should have radial shape, and the stronger magnetic field the more vertical. LB is another magnetic system, the distribution of magnetic field line should be more inclined. Thus, the plasma flow the field line of individual magnetic system of sunspot and LB. The fine topology of magnetic field of LB is

unknown for us due to the restrictions of observatory. Maybe the field lines along the axis of LB or field lines surround the axis of LB. Hence the plasma maybe flow along the axis of LB or they surround the axis of LB. Either field lines along LB or they surround LB, they should be considered as another magnetic system comparing to that of main sunspot, which different from the main sunspot. Thus, there can exist the basic condition for magnetic reconnection at the boundary between sunspot and LB, and jet unavoidable become the results of magnetic reconnection.

Hinode is a Japanese mission developed and launched by ISAS/JAXA, collaborating with NAOJ as a domestic partner, NASA and STFC (UK) as international partners. Scientific operation of the *Hinode* mission is conducted by the *Hinode* science team organized at ISAS/JAXA. This team mainly consists of scientists from institutes in the partner countries. Support for the post-launch operation is provided by JAXA and NAOJ (Japan), STFC (U.K.), NASA, ESA, and NSC (Norway). This work was partly supported by the National Natural Science Foundation of China (Grant Nos. 10611120338, 10673016, 10733020, 10778723, 11003025, 11103037 and 10878016), National Basic Research Program of China (Grant No. 2011CB8114001) and Important Directional Projects of Chinese Academy of Sciences (Grant No. KLCX2-YW-T04).

aastex-help@aaas.org.

REFERENCES

- Asai, A., Ishii, T.T., & Kurokawa, H. 2001, ApJ, 555, L65
- Bharti, T., Rimmele, T., Jain, R., Jaaffrey, S.N.A., & Smart, R.N. 2007, MNRAS, 376, 1291
- Berger, T.E. & Berdyugina, S.V. 2003, ApJ, 589, L117
- Bray, R.J. & Loughhead, R.E. 1964, Sunspots, The International Astrophysics Series (London: Chapman & Hall)
- Boerner, P., Soufli, R., Podgorski, W. & Wolfson, C. J. 2010, AGU Fall Meeting Abstracts, 1871
- Garcia de La Rosa, J.I. 1987, Sol. Phys., 112, 49
- Garcia de La Rosa, J.I. 1987, Sol. Phys., 112, 49
- Louis, P.E., Bayanna, A.R. & Mathew, S.K. 2008, Sol. Phys., 252, 43
- Jurcak, J., Pillet, V.M., & Sobotka, M. 2006, A&A, 112, 49
- Katsukawa, Y. 2007, New Solar Physics with Solar-B Mission ASP Conference Series, Edited by Kazunari Shibata, Shin'ichi Nagata, Takashi Sakurai, 369, p.287
- Katsukawa, Y., Yokoyama, T., Berger, T.E., Ichimoto, K., Kubo, M., Lites, B.W., Nagata, S., Shimizu, T., A.Shine, R., Suematsu, Y., D.Tarbell, T., M.Title, A. & Sueta, S. Katsukawa, Y., 2007, PASJ, 59, 577
- Kosugi, T., Matsuzaki, K., Sakao, T., Shimizu, T., Sone, Y., Tachikawa, S., Hashimoto, T., Minesugi, K., Ohnishi, A., Yamada, T., Tsuneta, S., Hara, H., Ichimoto, K., Suematsu, Y., Shimojo, M., Watanabe, T., Davis, J.M., Hill, L.D., Owens, J.K.,

- Title, A.M., Culhane, J.L., Harra, L., Doschek, G.A., & Golub, L. 2007, *Sol. Phys.*, 243, 3
- Leka, K.D. 1997, *ApJ*, 484, 900
- Ruedi, I., Solanki, S.K. & Livingston, W. 1979, *Sol. Phys.*, 61, 297
- Muller, R. 1979, *Sol. Phys.*, 61, 297
- Roy, J.-R. 1973, *Sol. Phys.*, 28, 95
- Sobatka, M., Bonet, J.A. & Vazquez, M. 1993, *ApJ*, 415, 832
- Sobatka, M., Bonet, J.A. & Vazquez, M. 1994, *ApJ*, 426, 404
- Schou, J., Borrero, J. M., Norton, A. A., Tomczyk, S., Elmore, D. & Card, G. L. 2010, *Sol. Phys.*, 177
- Shimizu, T., Katsukawa, Y., Kubo, M., Lites, B.W., Ichimoto, K., Suematsu, Y., Tsuneta, S., Nagata, S., A.Shine, R., & D.Tarbell, T. 2009, *ApJ*, 696, L66
- Spruit, H.C., & Scharmer, G.B. 2006, *ApJ*, 415, 832
- Title, A. 2010, 38th COSPAR Scientific Assembly. Held 18-15 July 2010, in Bremen, Germany, p.2
- Tsuneta, S., Suematsu, Y., Ichimoto, K., Shimizu, T., Otsubo, M., Nagata, S., Katsukawa, Y., Title, A., Tarbell, T., Shine, R., Rosenberg, B., Hoffmann, C., Jurcevich, B., Levay, M., Lites, B., Elmore, D., Matsushita, T., Kawaguchi, N., Mikami, I., Shimada, S., Hill, L., & Owens, J. 2008, *Sol. Phys.*, 249, 167
- Vasquez, M. 1973, *Sol. Phys.*, 31, 377

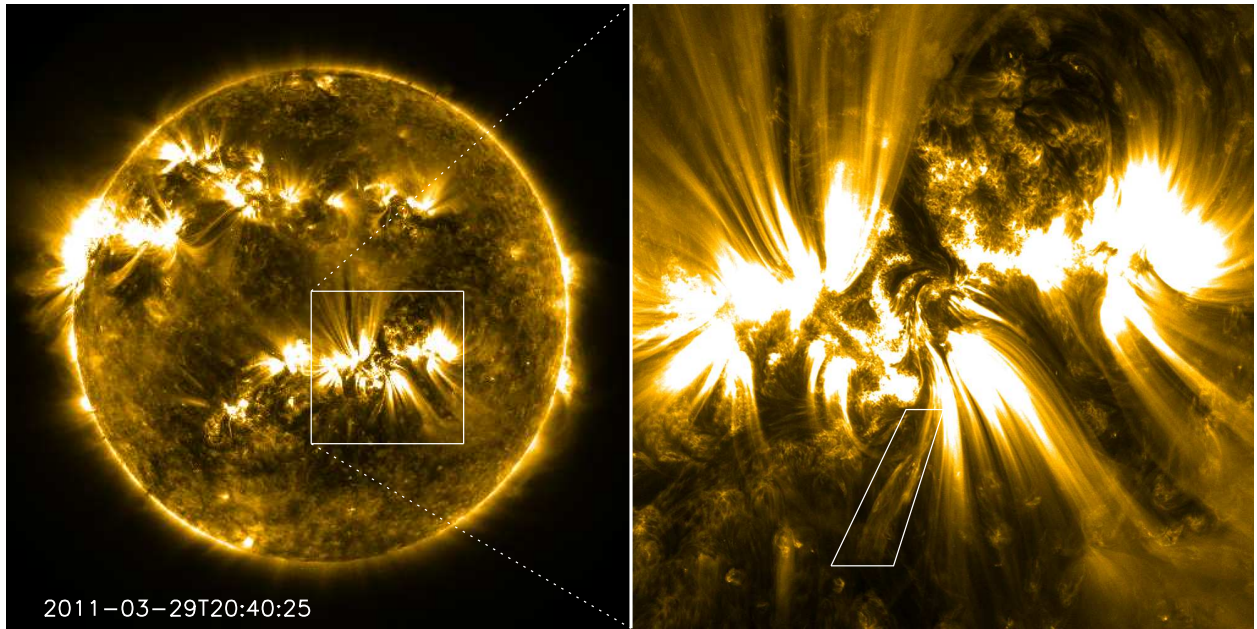


Fig. 1.— The left image is full-disk AIA 171 image at 20:40;25 UT on 03 29 2011. The right one is sub-region drawn in the left image, where coronal jet is highlighted by a rectangle drawn in right image.

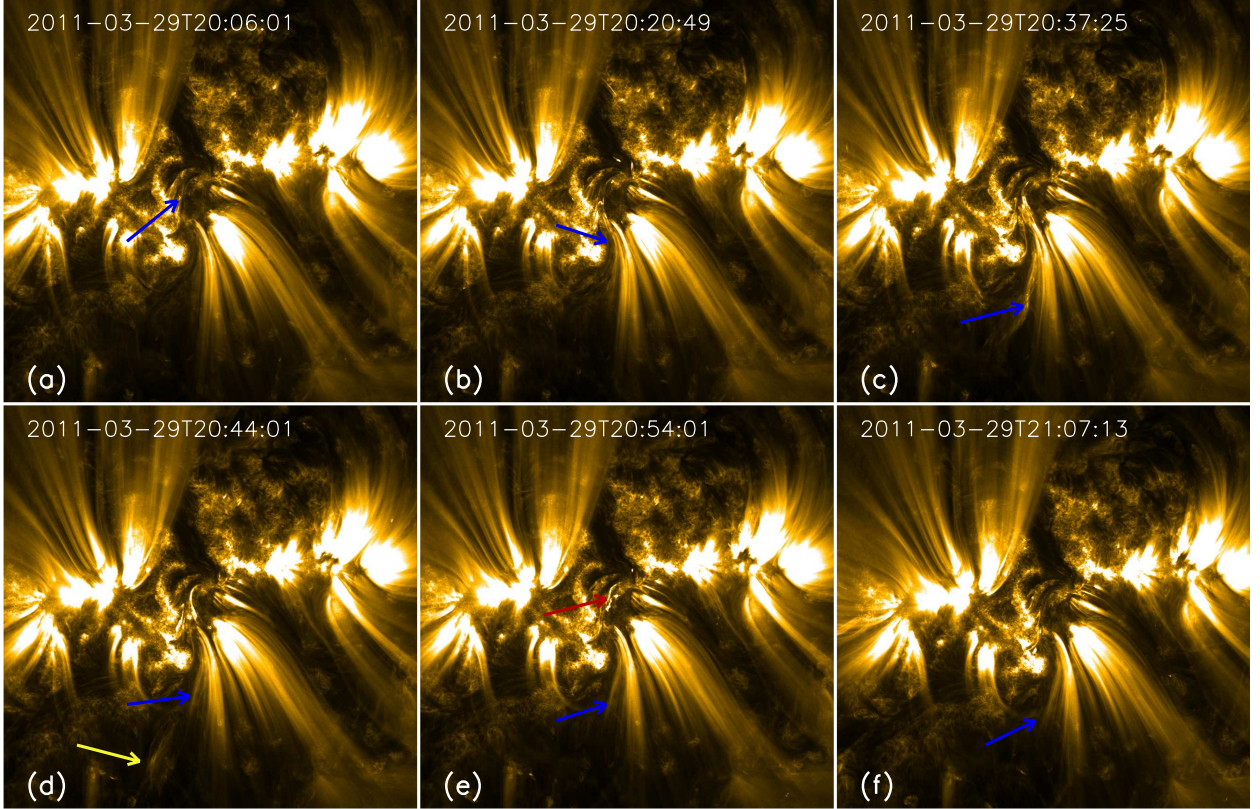


Fig. 2.— Time series images of AIA 171 channel which show the process of jet. It includes the start (a, b), maximum (c, d) and decay (e, f) phases. It can be seen in image (d) that the jet have already separated two parts along its direction of propagation.

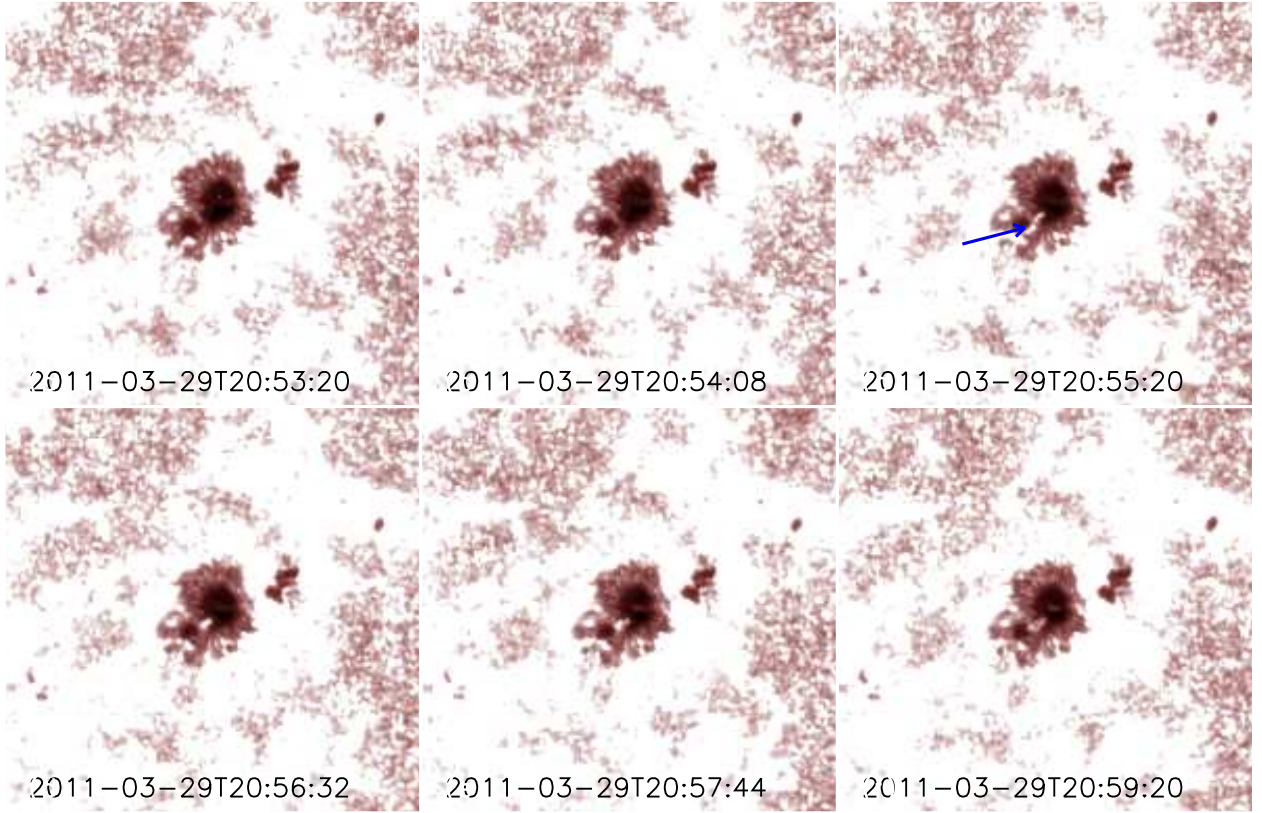


Fig. 3.— The evolution of 1700 Å images from 20:53 to 20:59 UT, the blue arrow in panel (e) should be caused by the back-flow of jet.

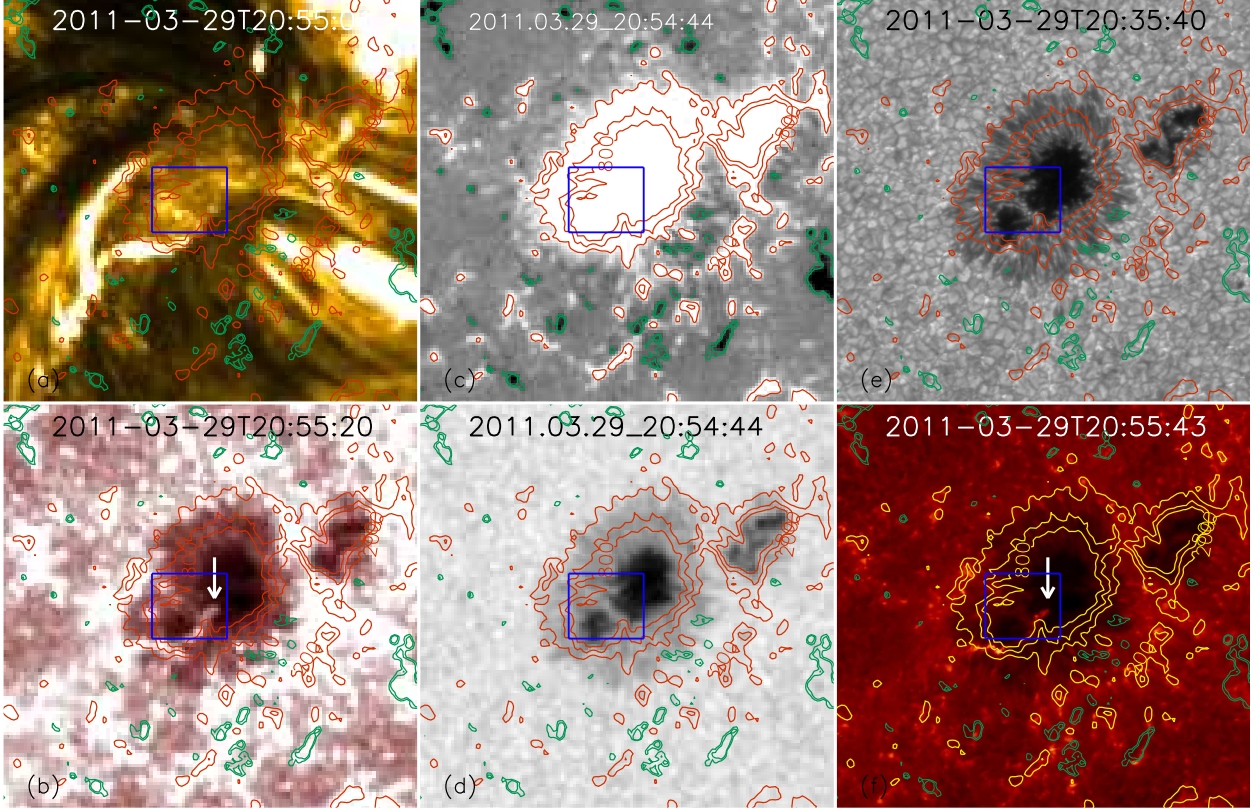


Fig. 4.— The 171 Å (a) and 1700 Å (b) AIA images, LOS magnetogram (c) and continuum intensity (d) HMI images and G-band (e) and Ca II (f) *Hinode* images. The contours drawn on each image are light-of-sight magnetic field, where the levels of magnetic field contours are -80 to -50 and 200-800 G.

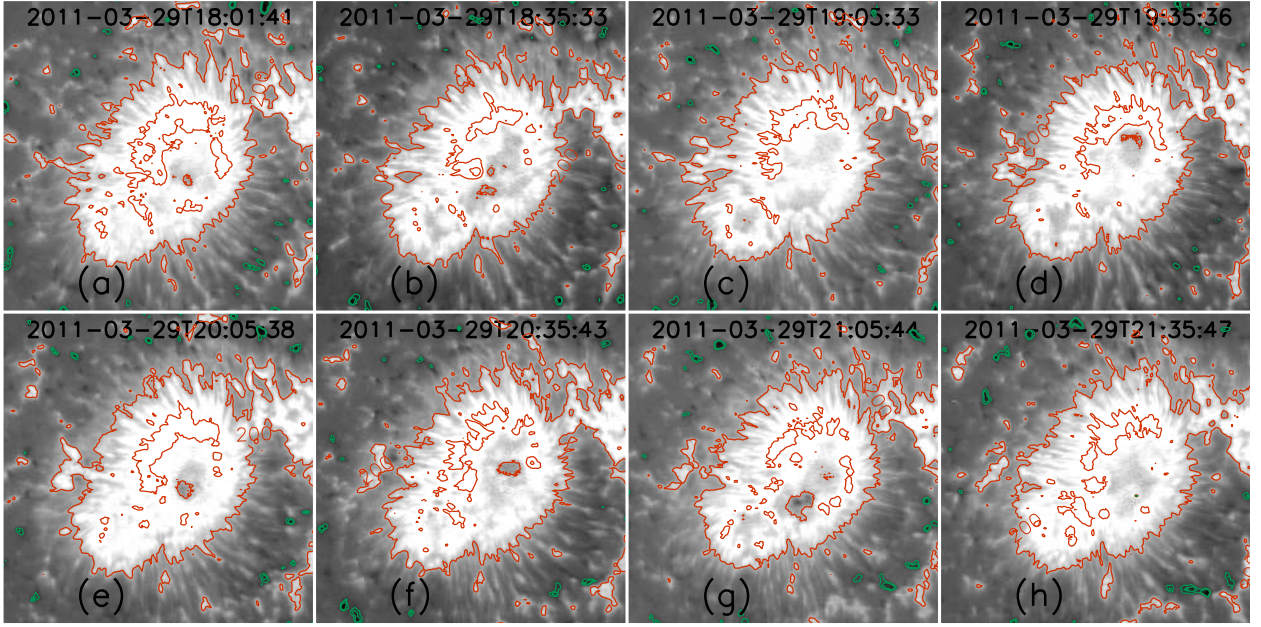


Fig. 5.— The evolution of LOS magnetic field observed by SOT/*Hinode* during 18:01-21:35 UT. The contours levels are from -80 to -50 (green) and 200-800 (red) G, and the field of view is $40 \times 40 \text{ arcsec}^2$. From these images it is found that comparing the magnetic flux of main sunspot there is no opposite magnetic flux near LB.

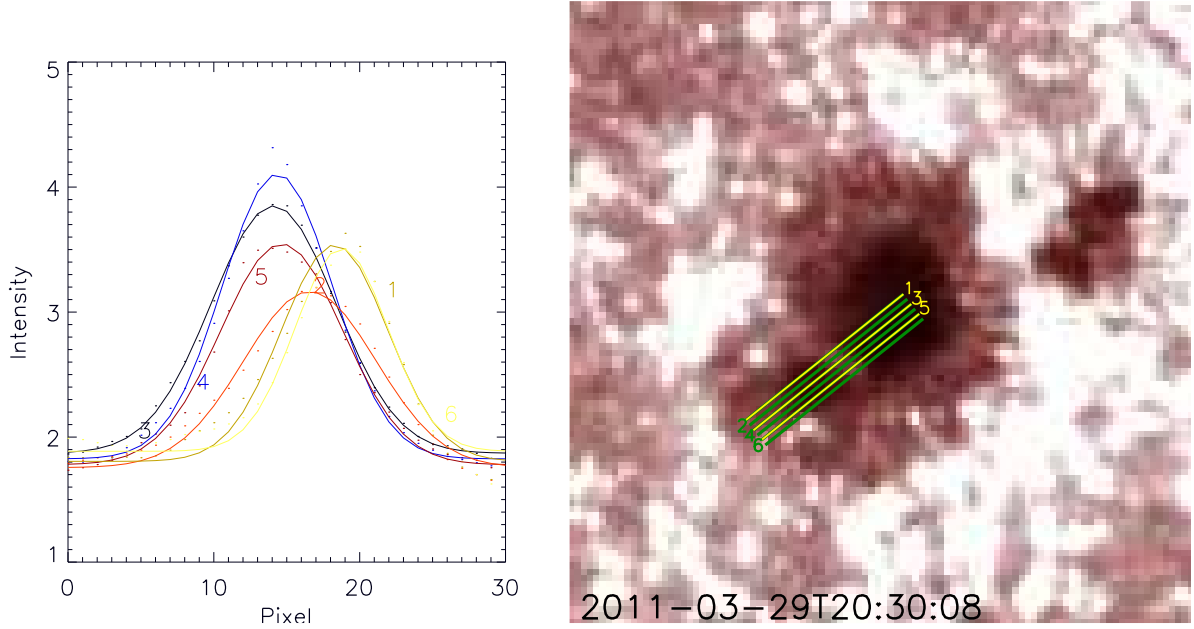
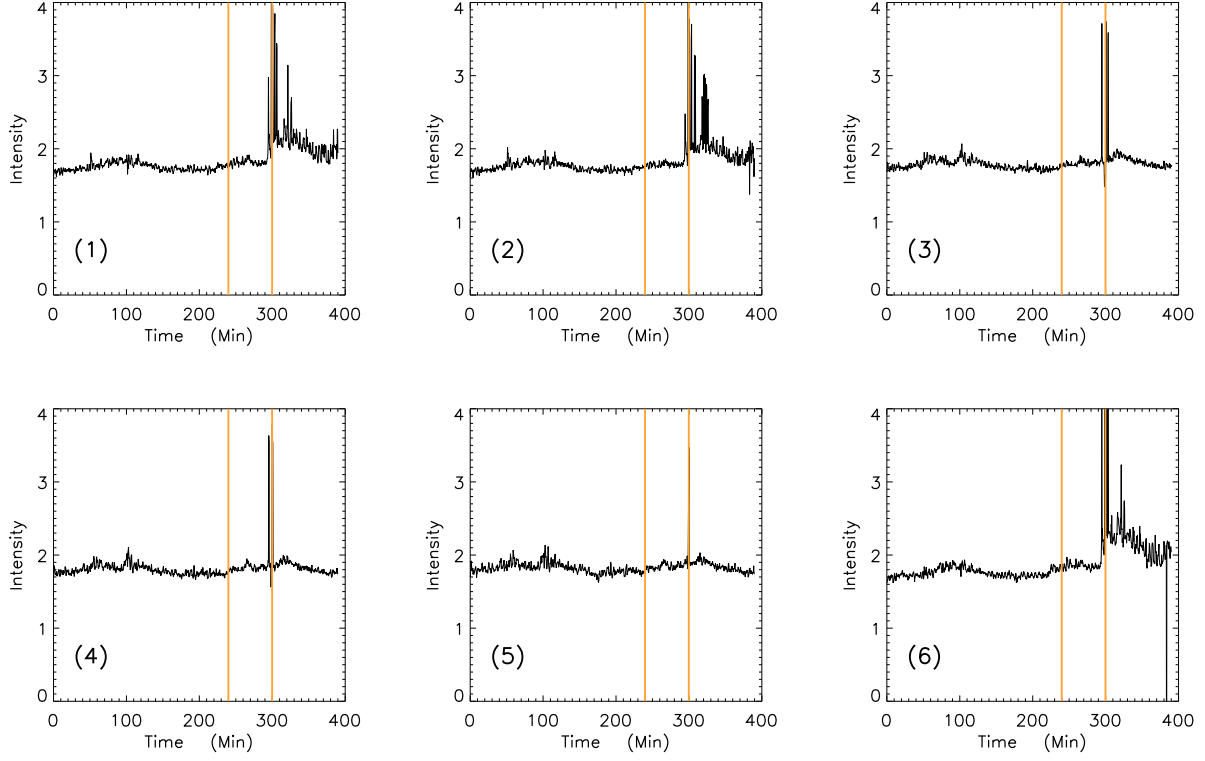
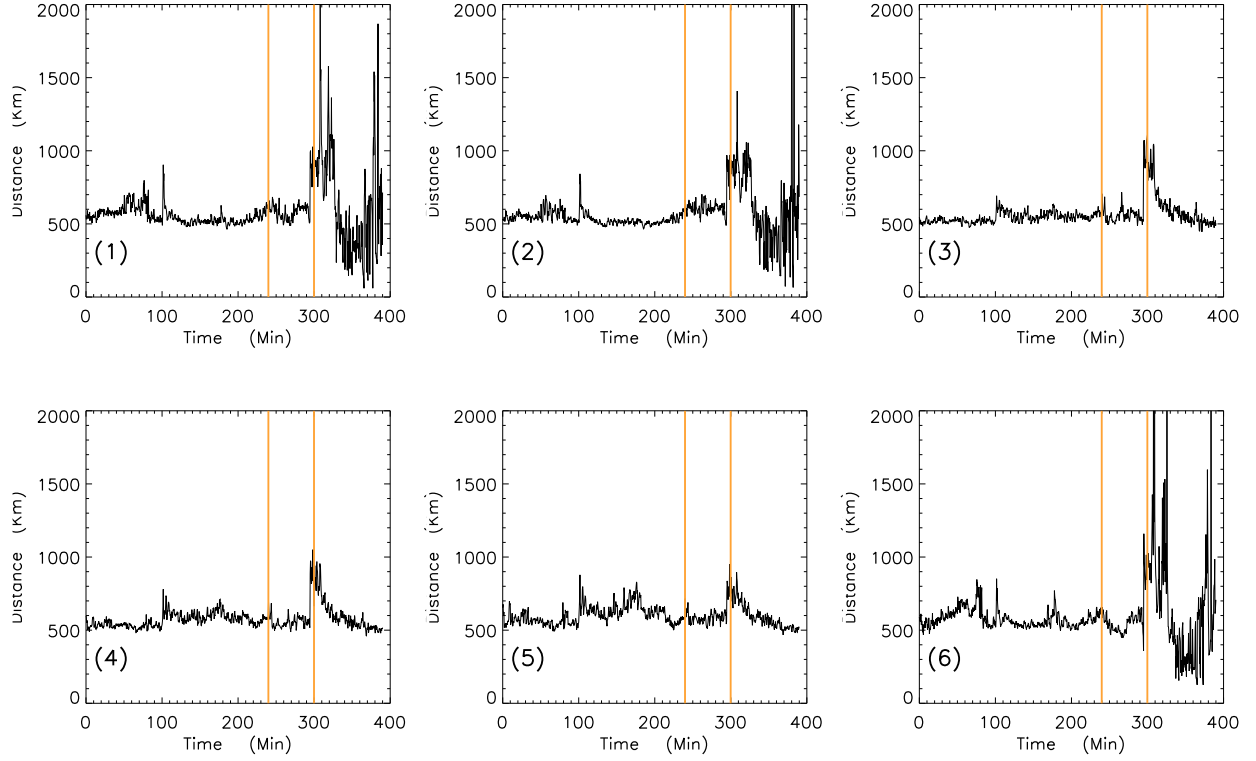


Fig. 6.— The right frame is example of 1700Å image, shows six selected slits along LB. The left frame plots the intensity of slits, and the profile of intensity obtained from Gaussian fit. The dot line is profile of intensity and solid line is Gaussian fit, the numbers of slit are corresponding those of the profile of intensity labeled



2011-03-29 16:00--22:30

Fig. 7.— The evolution of maximal intensity along LB obtained from Gaussian fit of six slits in AIA 1700 Å images. The time interval between two yellow vertical lines is 20:00-21:00 UT.



2011-03-29 16:00--22:30

Fig. 8.— The evolution of width of LB obtained from Gaussian fit of six slits in AIA 1700 Å images. The time interval between two yellow vertical lines is 20:00-21:00 UT.

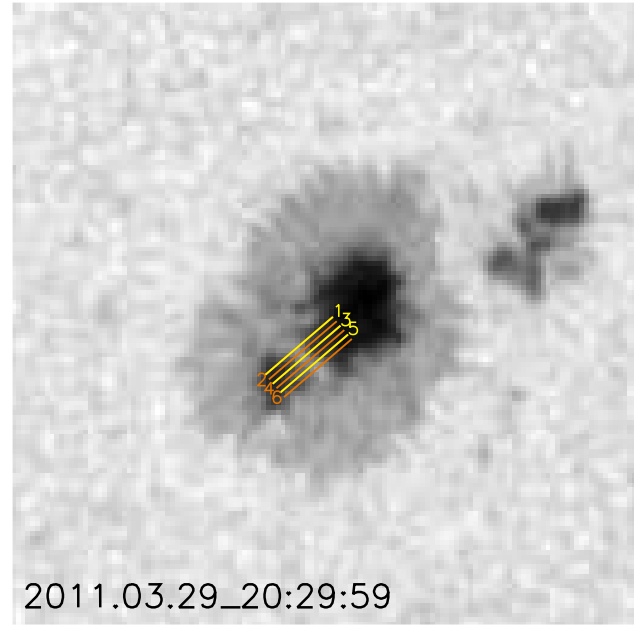
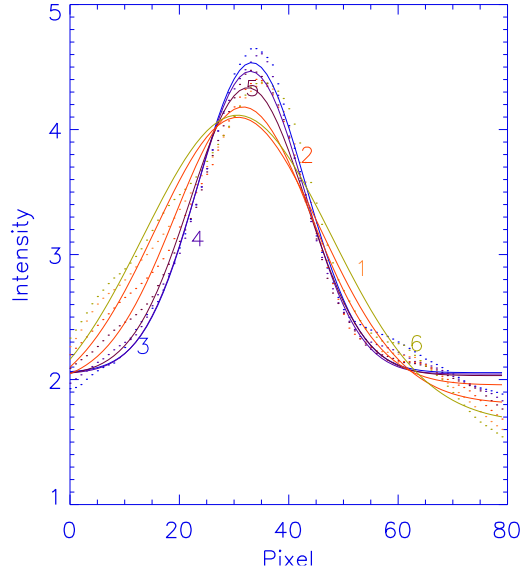
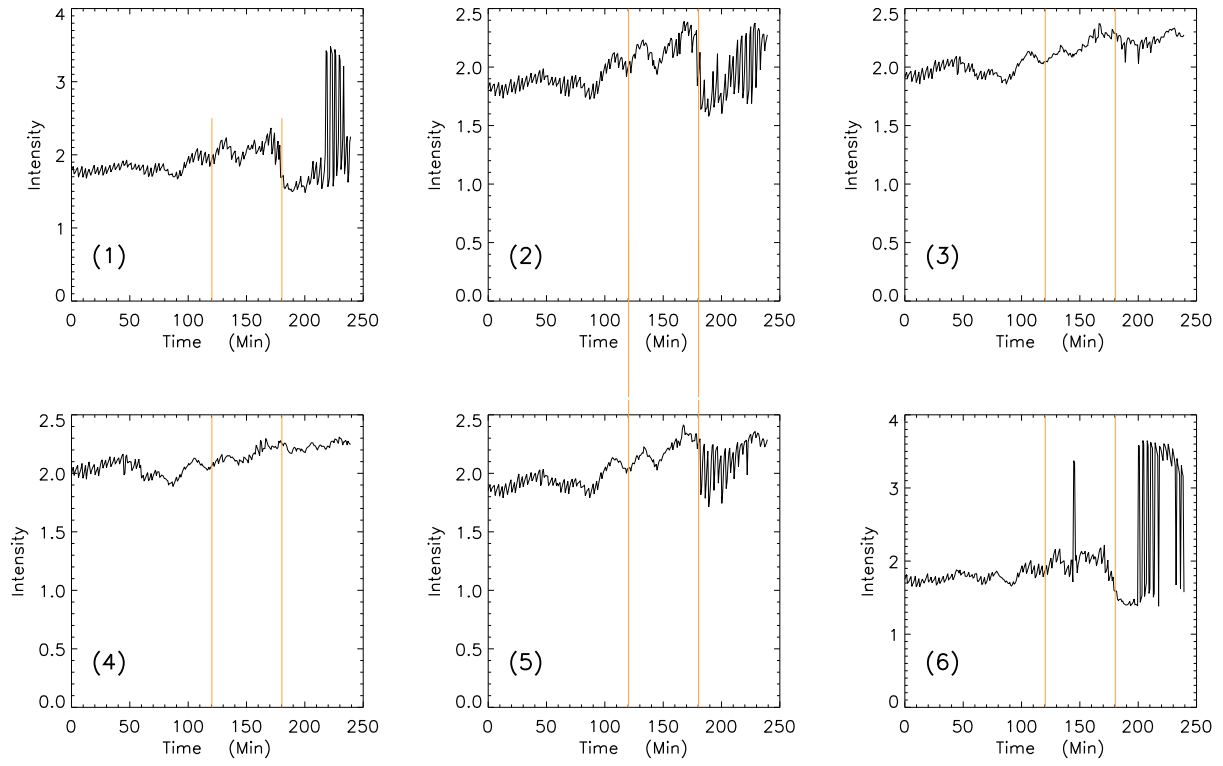


Fig. 9.— Same as Fig 5, but for HMI continuum intensity.



2011--03--29 18:00--21:59

Fig. 10.— Same as Fig 6, but for HMI continuum intensity.

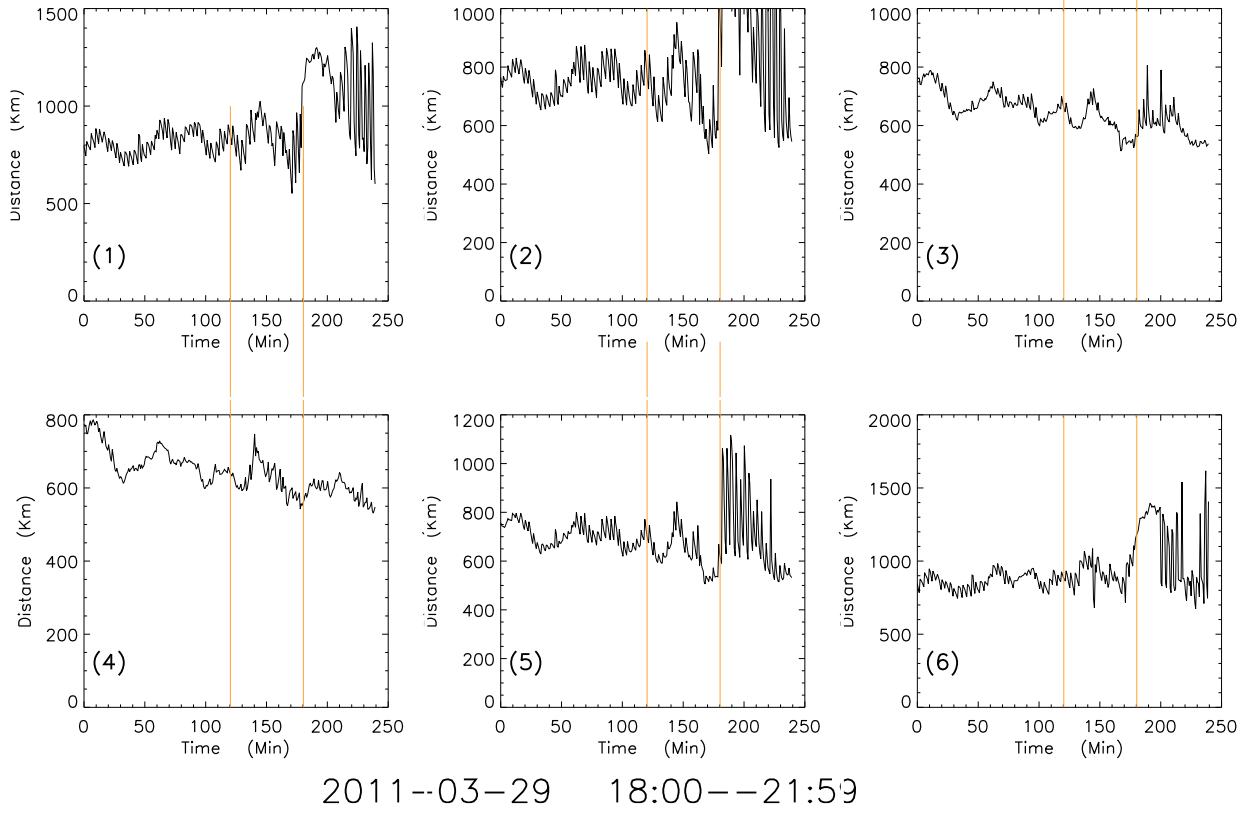


Fig. 11.— Same as Fig 7, but for HMI continuum intensity.